Frequency response measurements of an oscillating heat pipe using strain gauges

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Presented By
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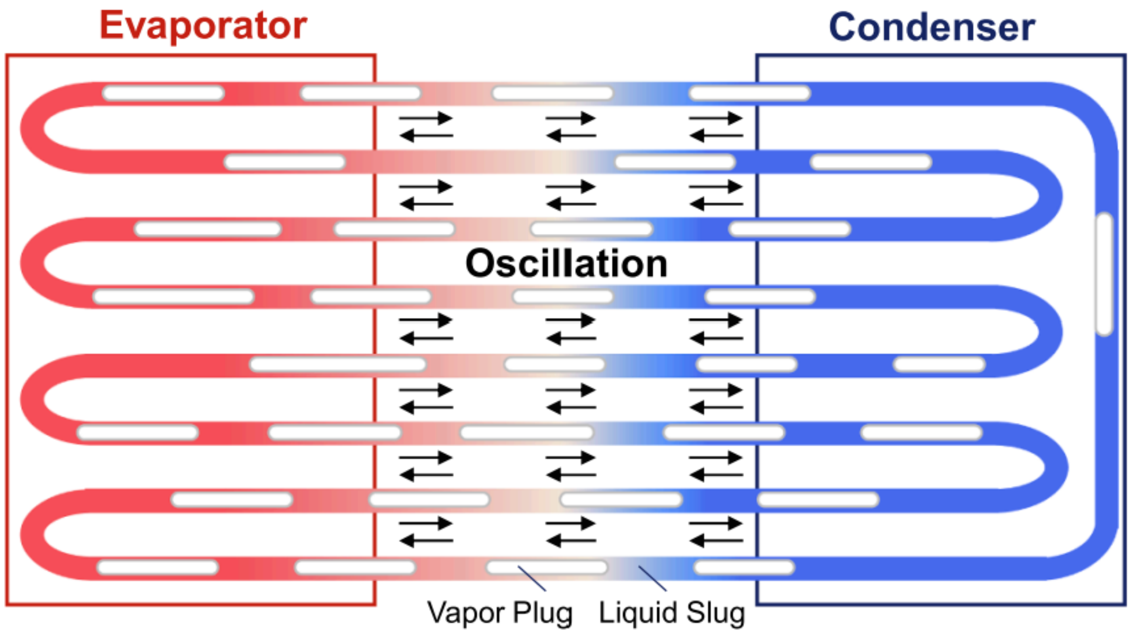
Oscillating heat pipes



K. Odagiri et al., *Appl. Therm. Eng.* (2021)

- Lightweight
- Cheap
- Good manufacturability
- Excellent heat transport capabilities

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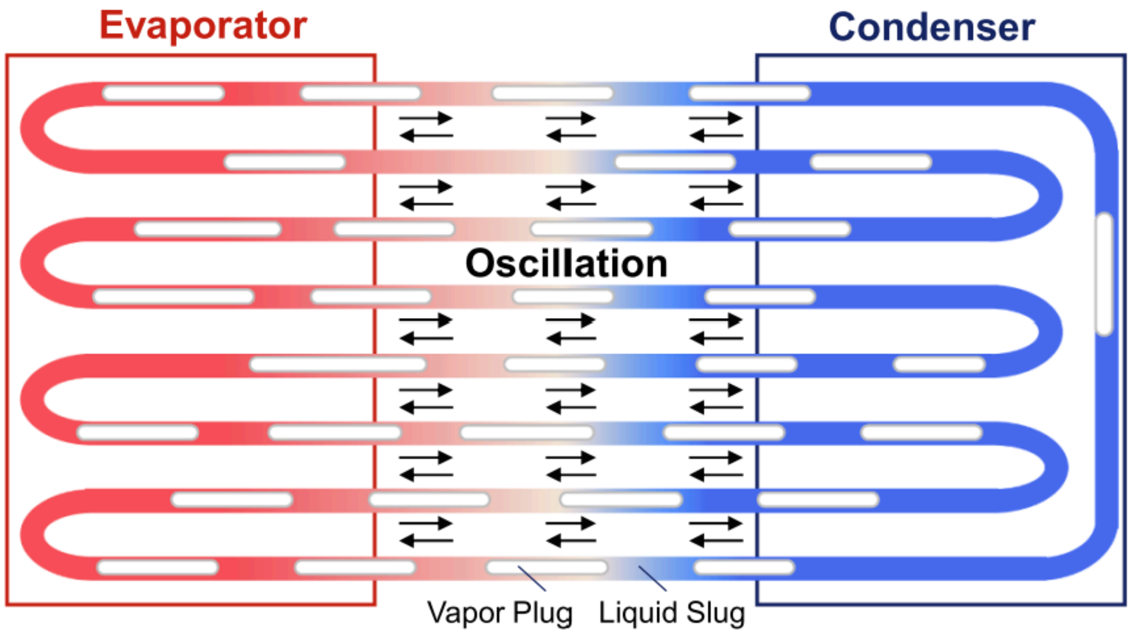

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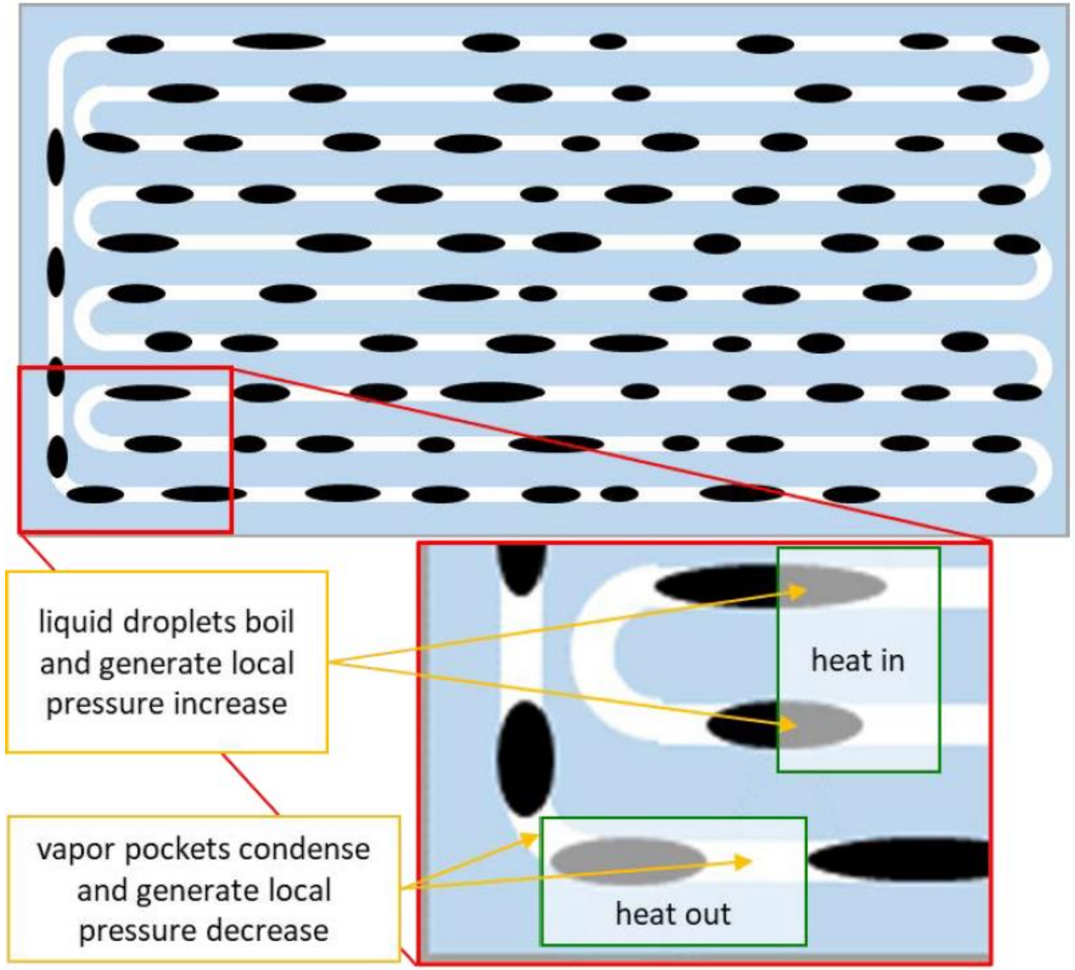
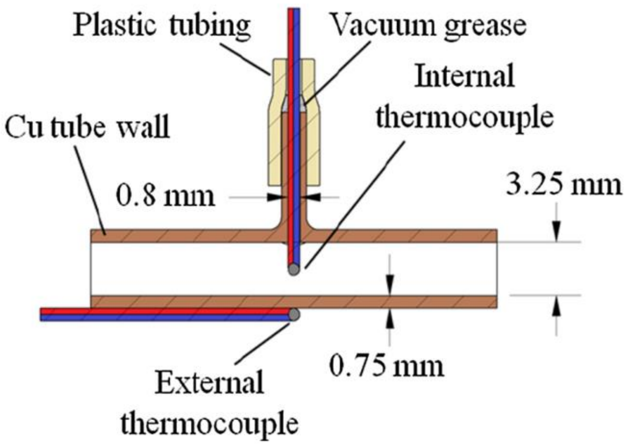
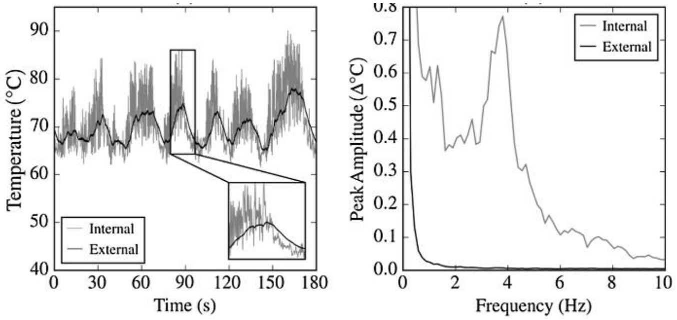


R. Wilcoxon et al., *(SEMI-THERM)* (2022)

Measuring the frequency of slug/plug oscillations

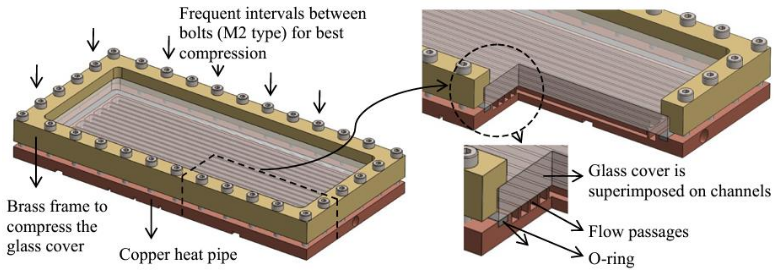
Intrusive sensors



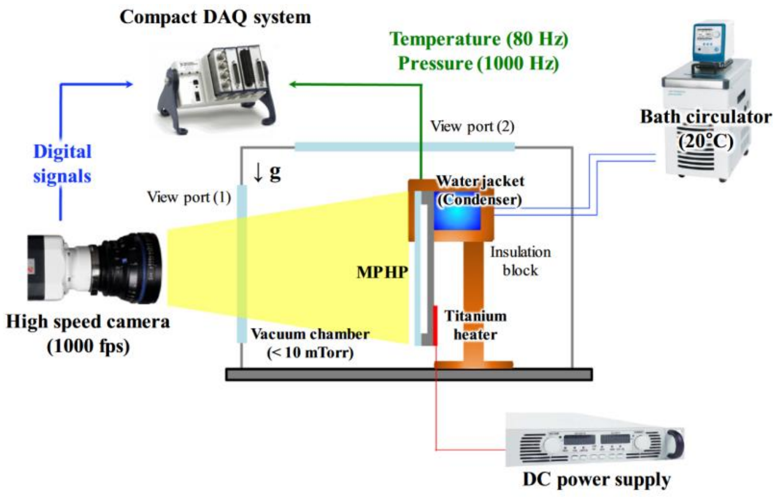


G.J. Monroe et al., *Exp. Therm. Fluid Sci.* (2017)

Transparent casings



B. Markal et al., *ICHMT.* (2021)



S. Jun & S.J. Kim, *IJHMT.* (2019)

Measuring the frequency of slug/plug oscillations

Intrus… …casings

Advantages and disadvantages of typical experimental techniques.

Experimental procedure	Advantages	Disadvantages
Temperature sensors placed on the outer wall	Straightforward installation.	Poor insight into the devices working behaviour.
Visible light imaging	Clear observation of the inner fluid dynamics.	High cost of high-speed and high-resolution cameras, great expertise required especially for temperature measurements. The need for transparent inserts will additionally increase the complexity of the experimental set-up. Absent or poor outcomes regarding the inner thermo-dynamics.
Neutron radiography	Clear observation of the inner fluid dynamics, even without any transparent inserts.	Extremely high cost of peripheral facilities.
IR visualization	Better description of the devices in terms of temperature distributions and operational behaviour.	High cost of IR cameras. The inner fluid dynamics cannot be satisfactorily observed when dealing with opaque walls.
Temperature and pressure sensors inserted in the fluid stream	Clear insight into the local thermos-fluid dynamic behaviour of the working fluid.	Sensors may locally perturb the fluid stream. Possible fluid leaks through the added junctions.

L. Pagliarini et al., *Exp. Therm. Fluid Sci.* (2023)

…IJHMT. (2021)

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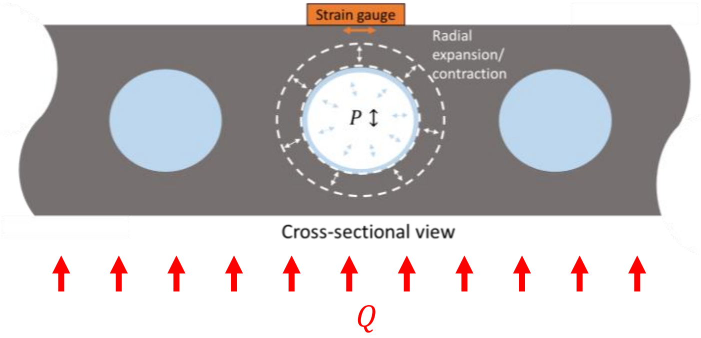
L. Pagliarini et al., *Exp. Therm. Fluid Sci.* (2023)

This work: strain gauges

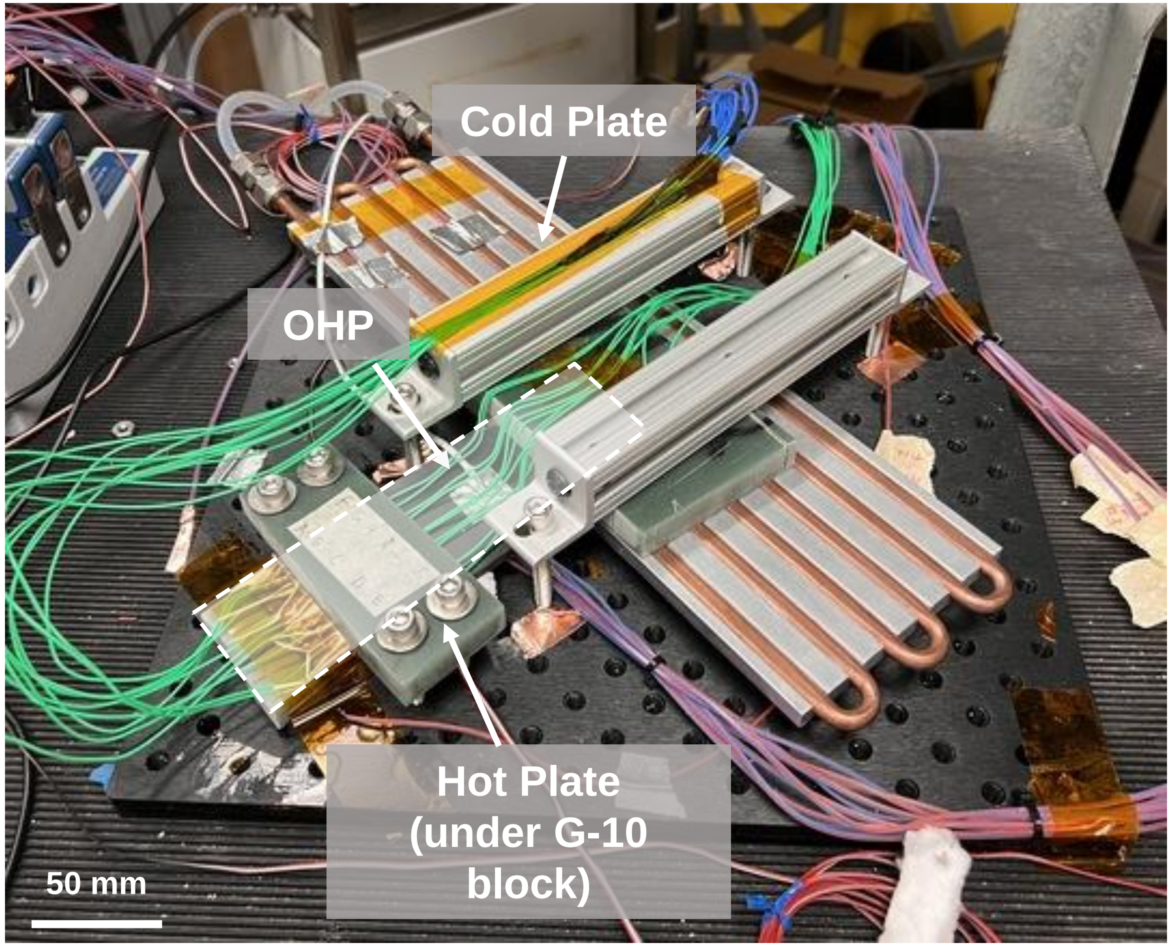


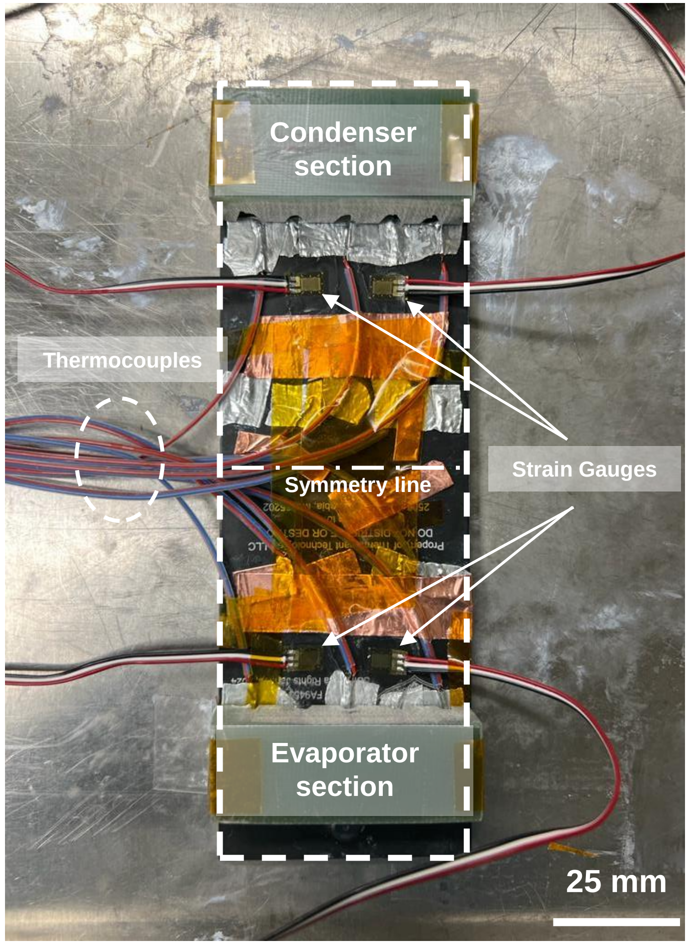
$$\tau_{\text{strain}} \sim t_{\text{casing}} / \sqrt{G_{\text{Al}} / \rho_{\text{Al}}} \approx 6.8 \times 10^{-4}\ \text{ms}$$

$$\tau_{\text{thermal}} \sim t_{\text{casing}}^2 / \alpha_{\text{Al}} \approx 56\ \text{ms}$$

T.J. Shimokusu et al., *Appl. Therm. Eng.* (2023)

Testbed for thermal and strain measurements

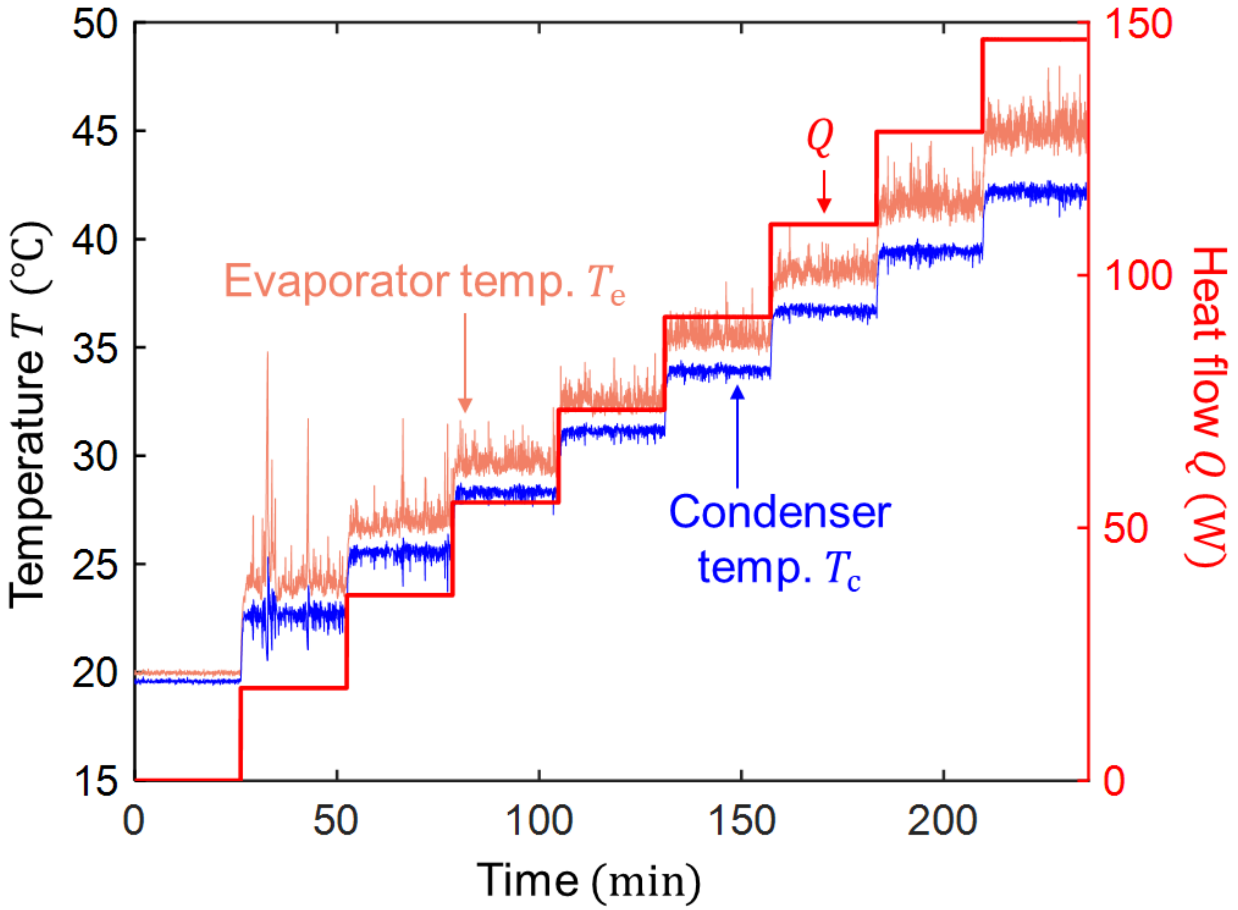


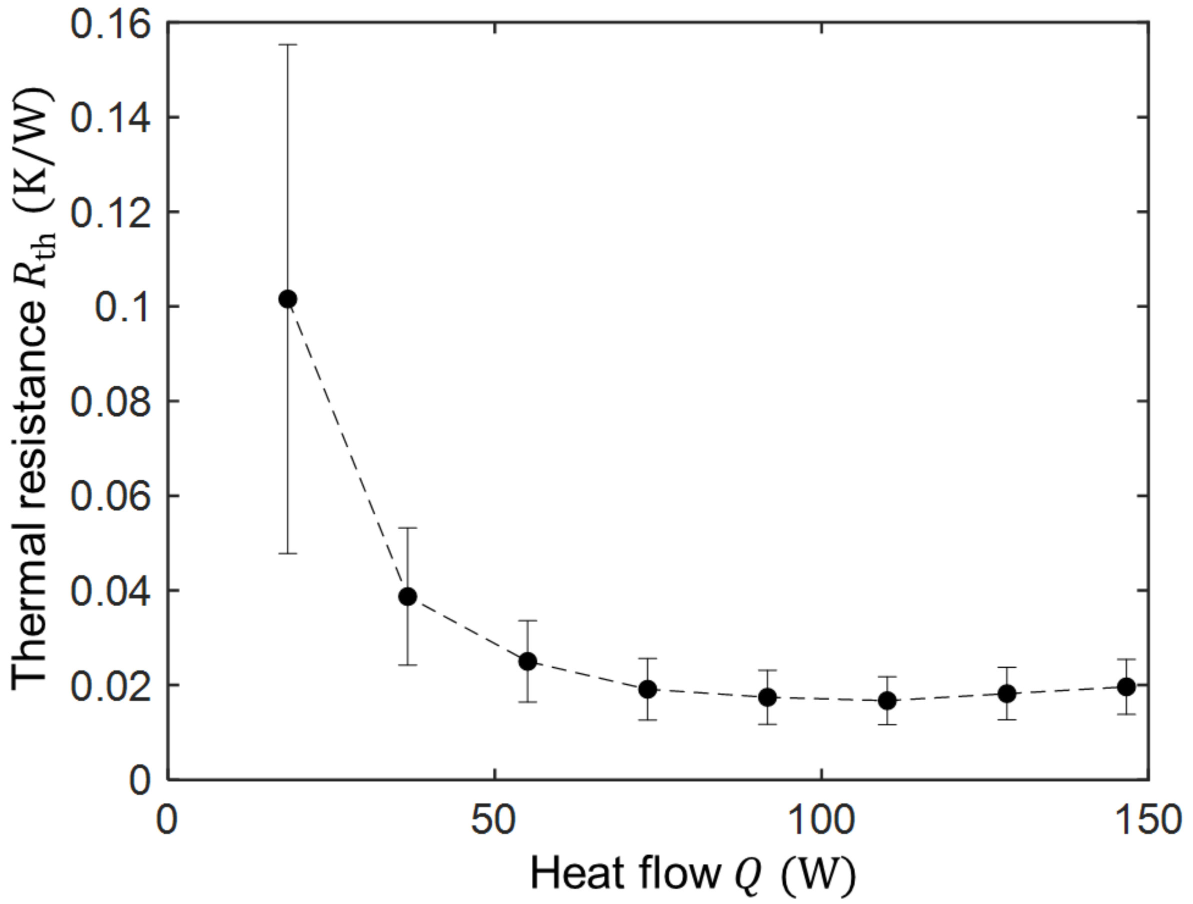


Notes on test parameters

- 34-turn closed-loop Al OHP filled with ammonia produced by ThermAvant
- Strain and temperature data acquired at 1000 S/s and 75 S/s rates, respectively, by NI DAQ modules and chassis
- Voltage data acquired by separate DAQ unit at ~0.3 Hz

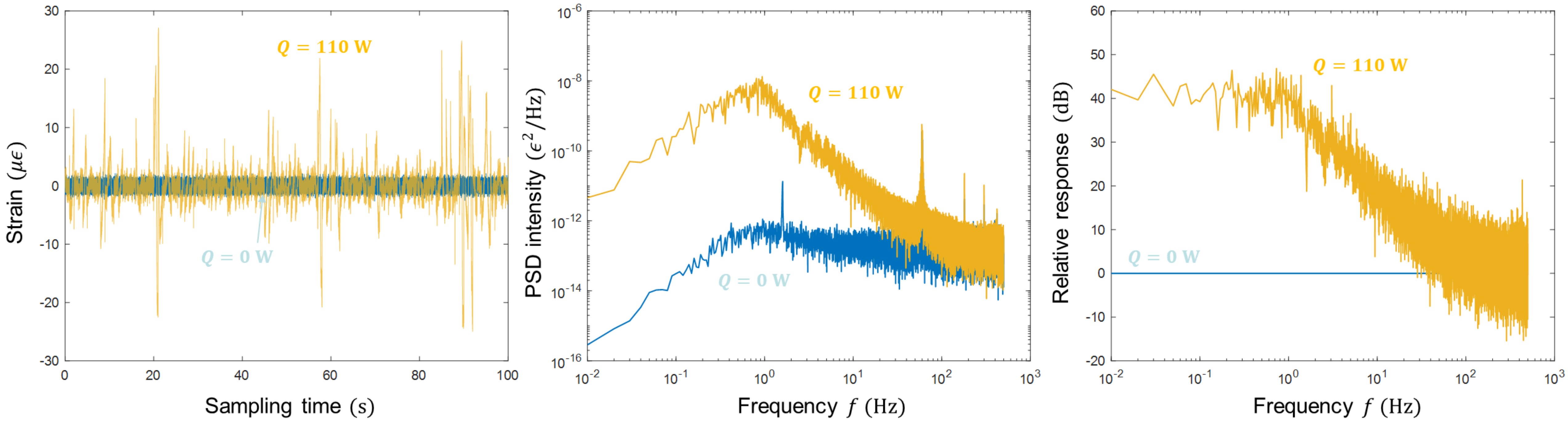
Representative thermal resistance data



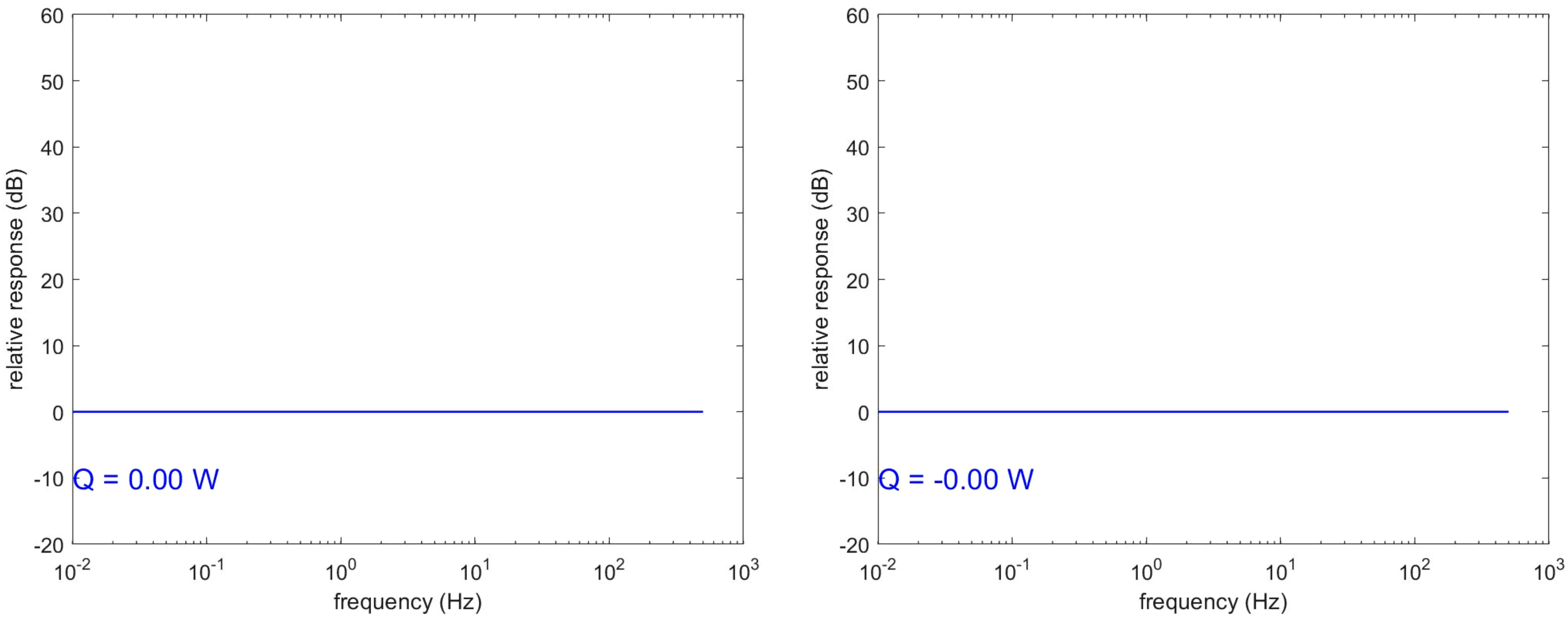


Fast Fourier transform

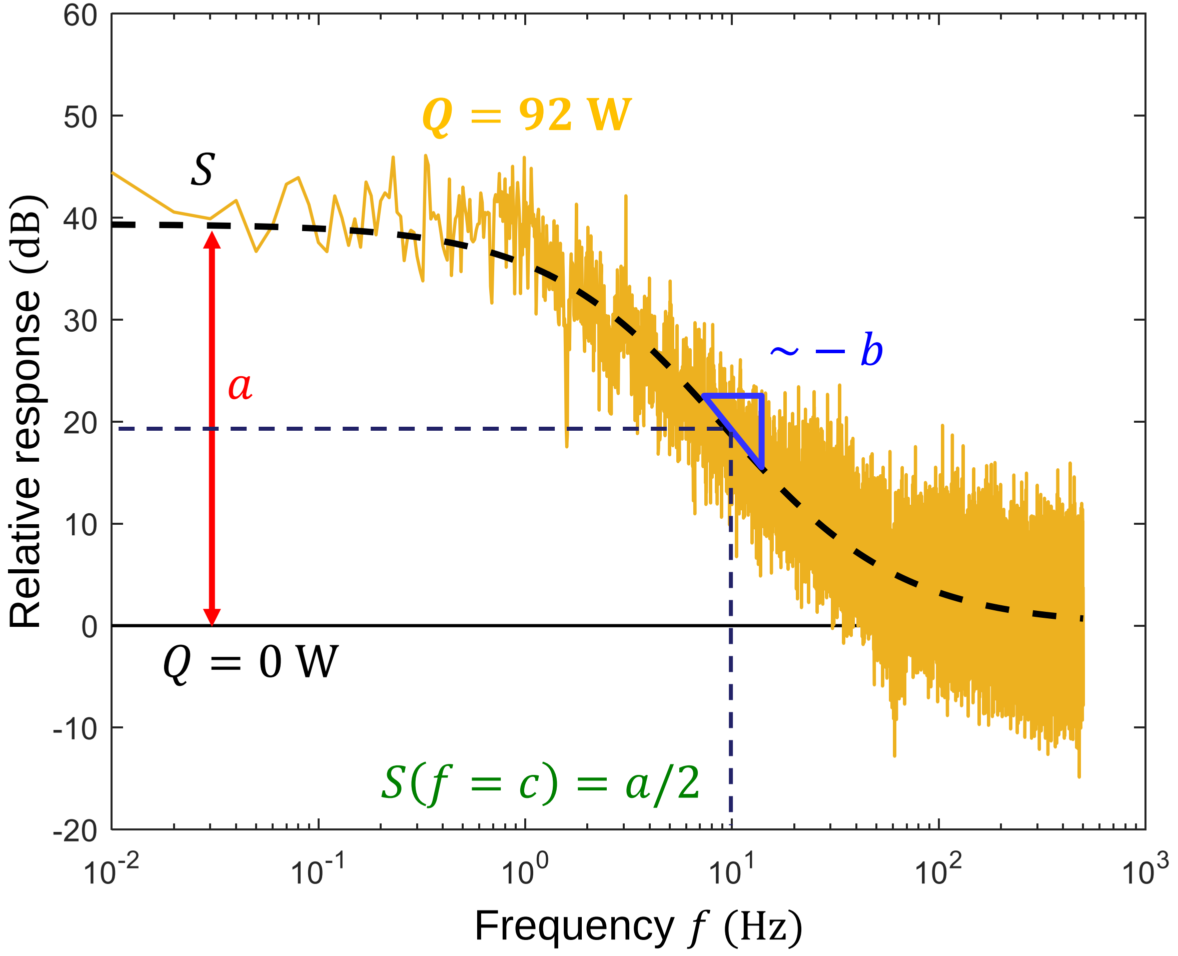
Relative response $= 10\log\left(\frac{PSD(Q)}{PSD(Q=0\ \mathrm{W})}\right)$



Frequency response evolution with Q



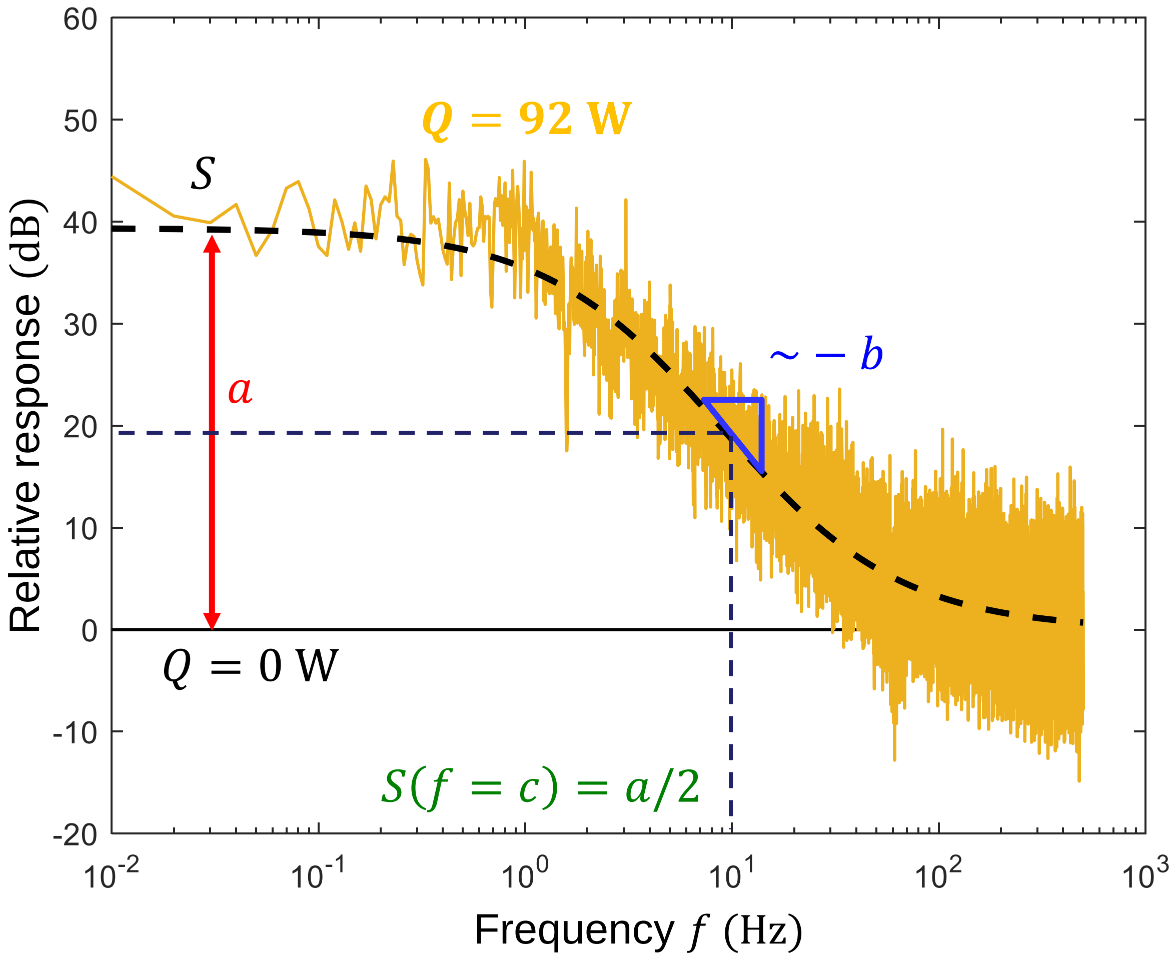
Quantifying the frequency response

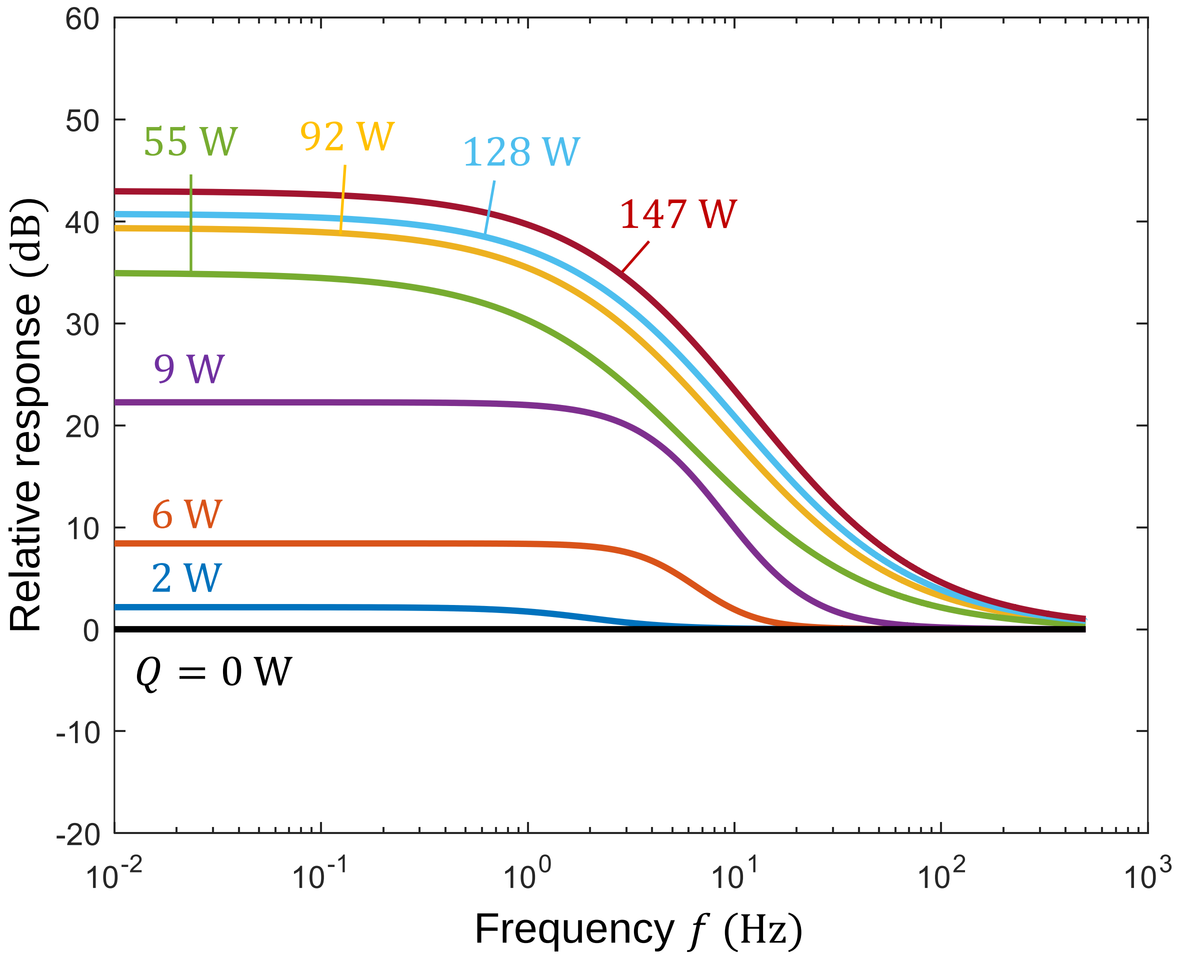


$$S(f) = \frac{a}{1 + \left(\frac{f}{c}\right)^{b}}$$

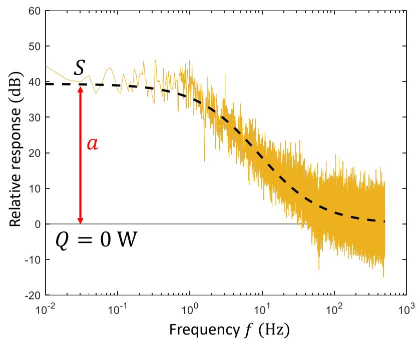
- a represents the upper plateau value of the curve, which reflects the characteristic signal-to-noise ratio
- b scales the slope of the curve at its midpoint, which corresponds to how fast the frequency response drops off
- c is frequency corresponding to the midpoint of the curve, and indicates a characteristic frequency

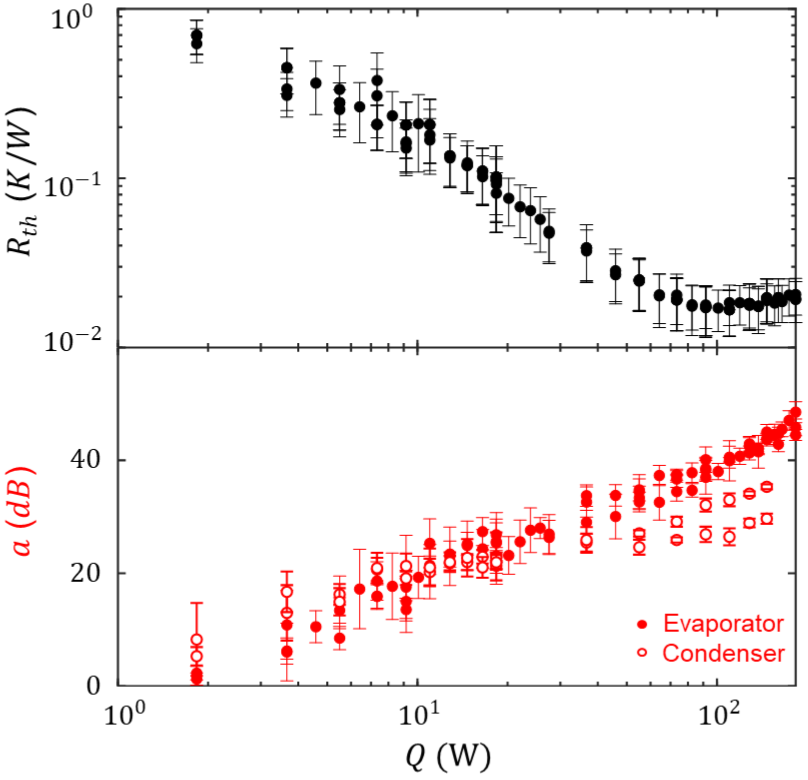
Quantifying the frequency response





a, b, c, and R_{th} as functions of Q





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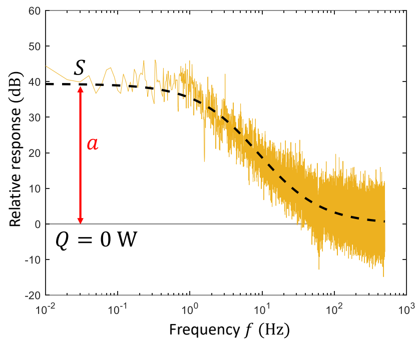

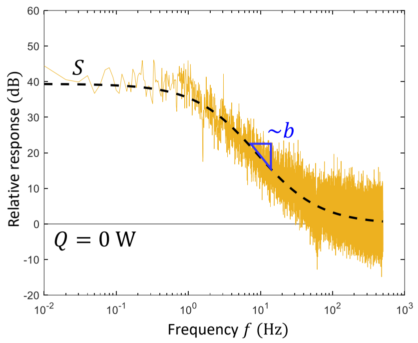

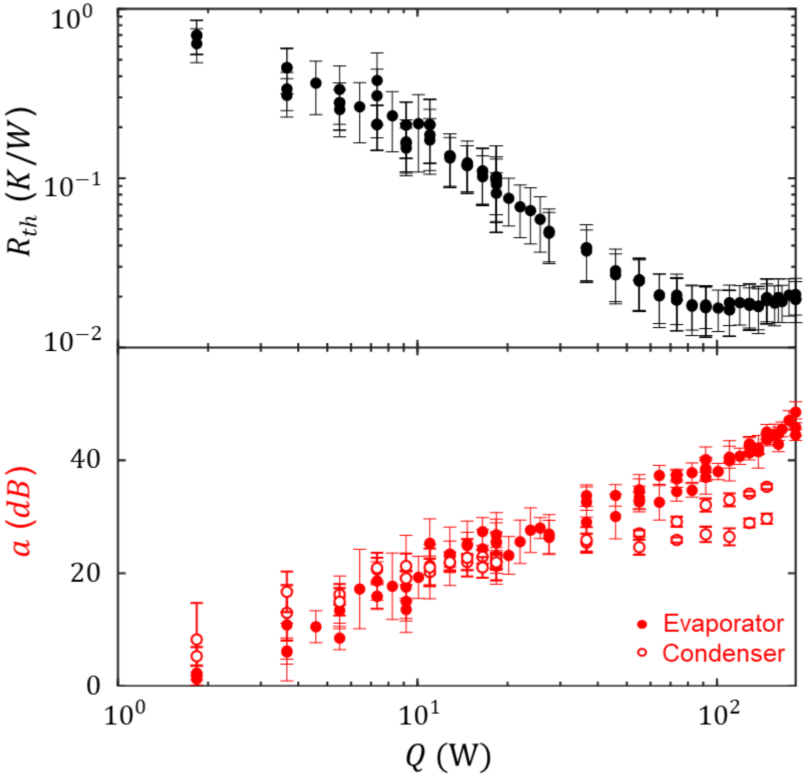

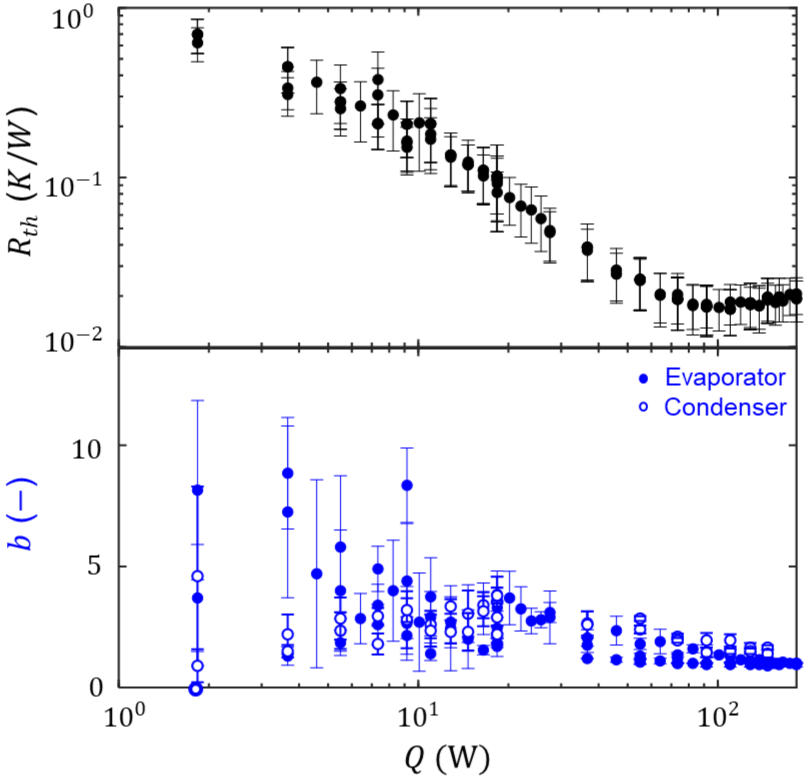

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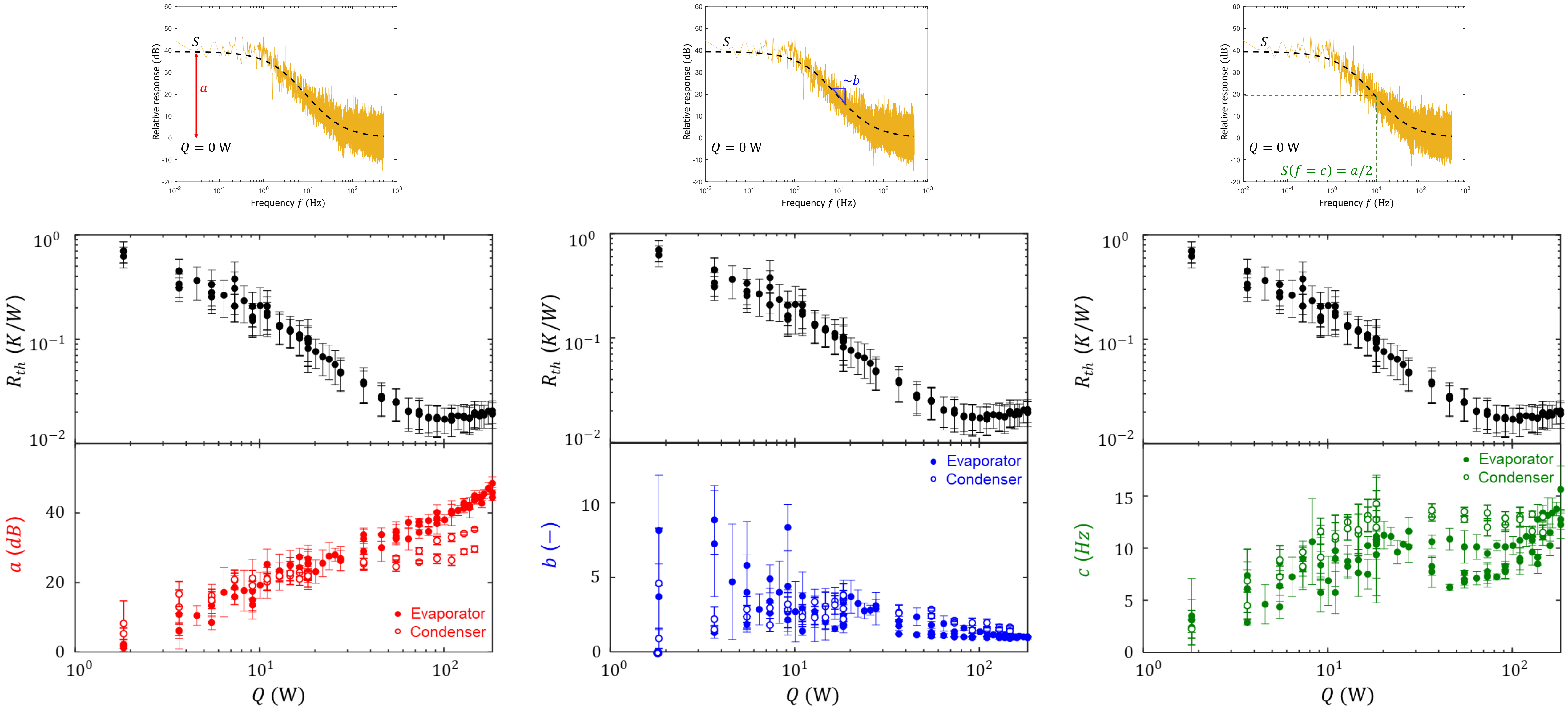
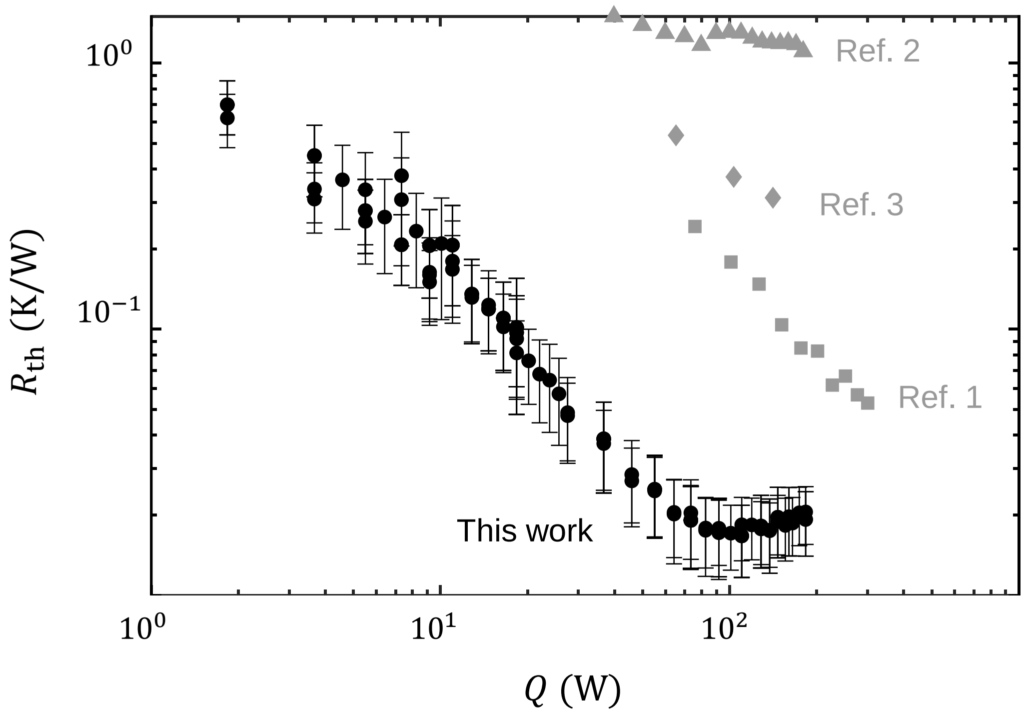
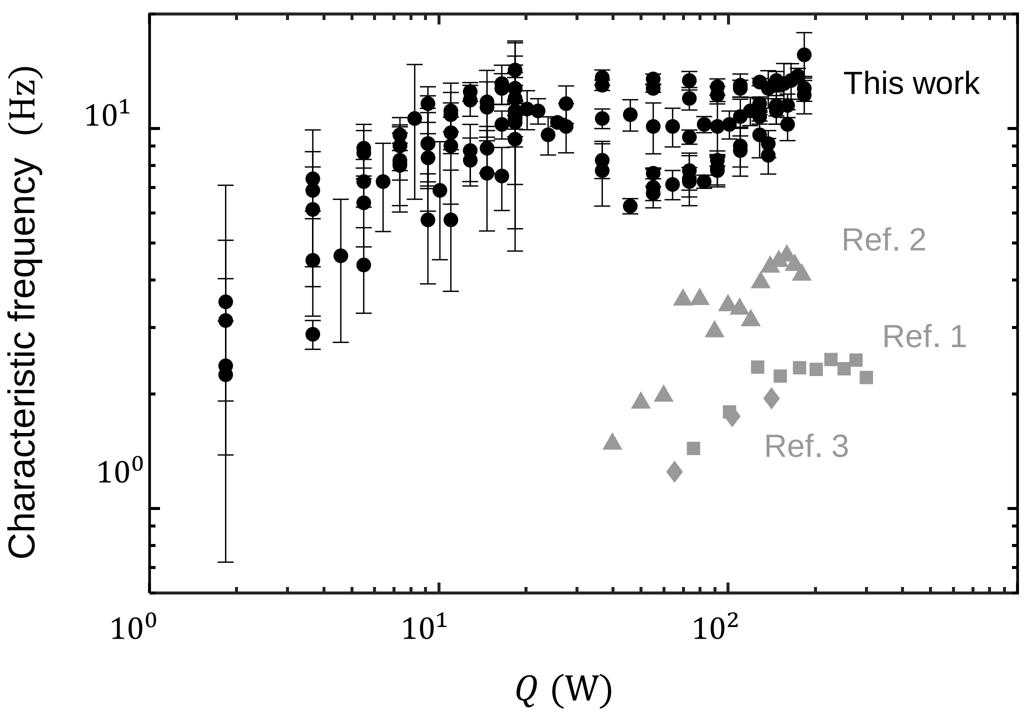


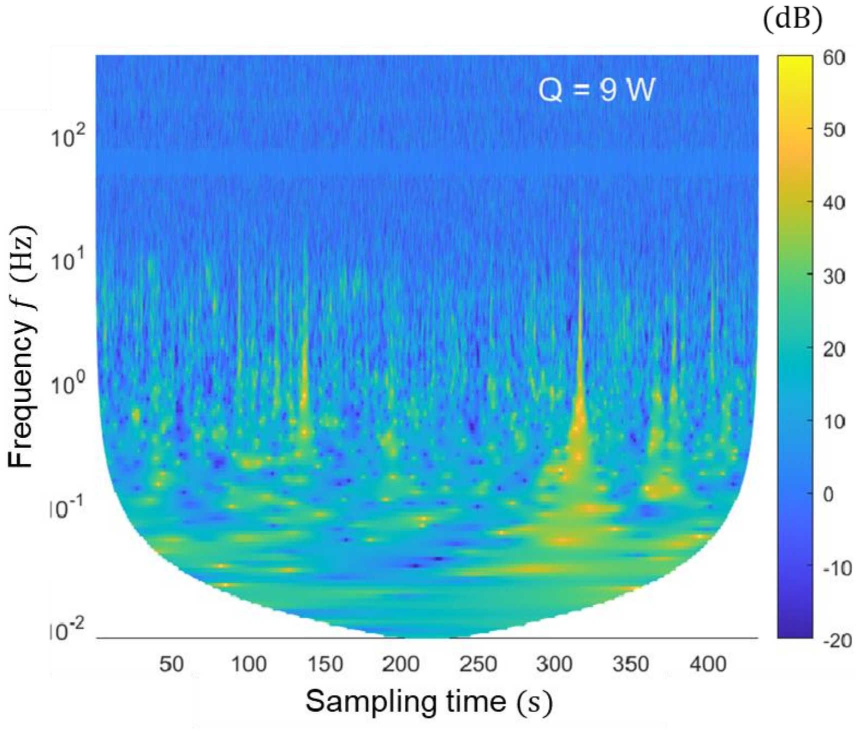
Frequency response: comparison with the literature





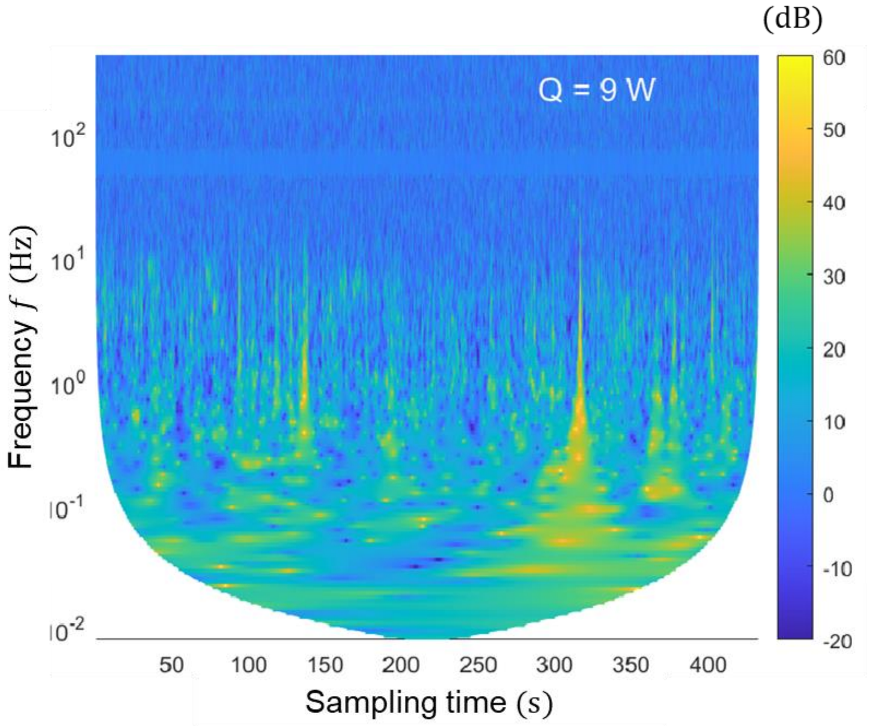
Ref. 1: J.G. Monroe et al., *Exp. Therm. Fluid Sci.* (2017)
Ref. 2: T. Daimaru & H. Nagai, *J. Thermophys. Heat Transf.* (2015)
Ref. 3: Y. Yasuda et al., *Int. J. Heat Mass Transf.* (2022)

Intermittent and stable operating regimes



Intermittent spikes in the frequency response at low Q

Intermittent and stable operating regimes



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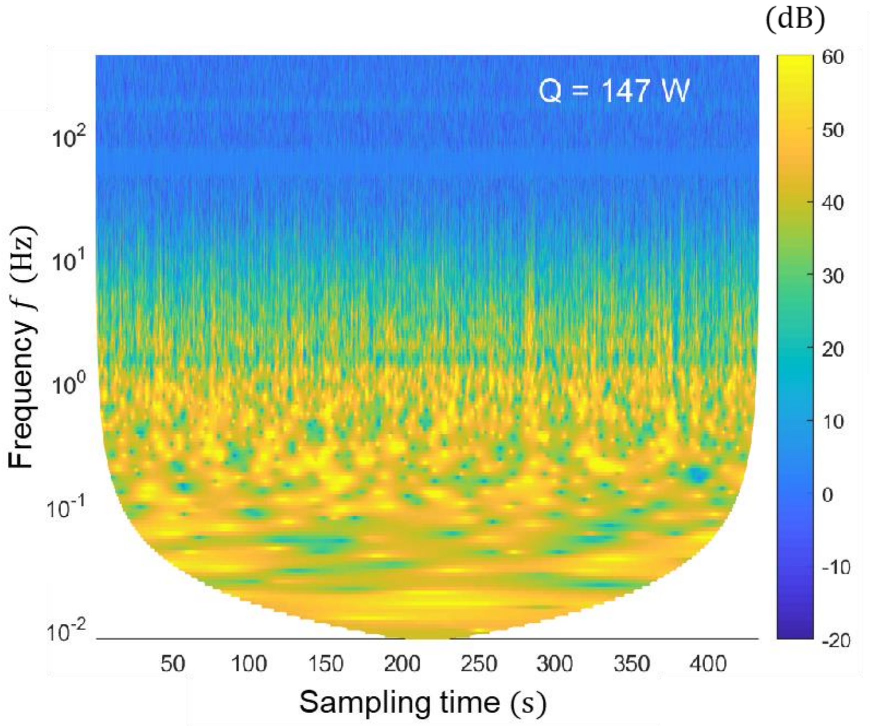

Stationary (temporally stable) response at high Q

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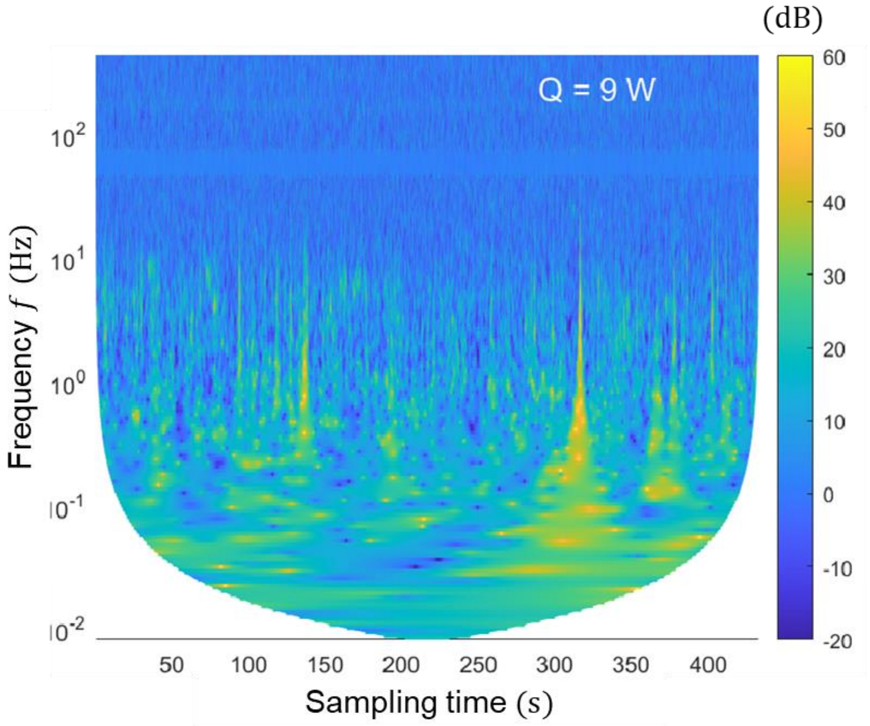

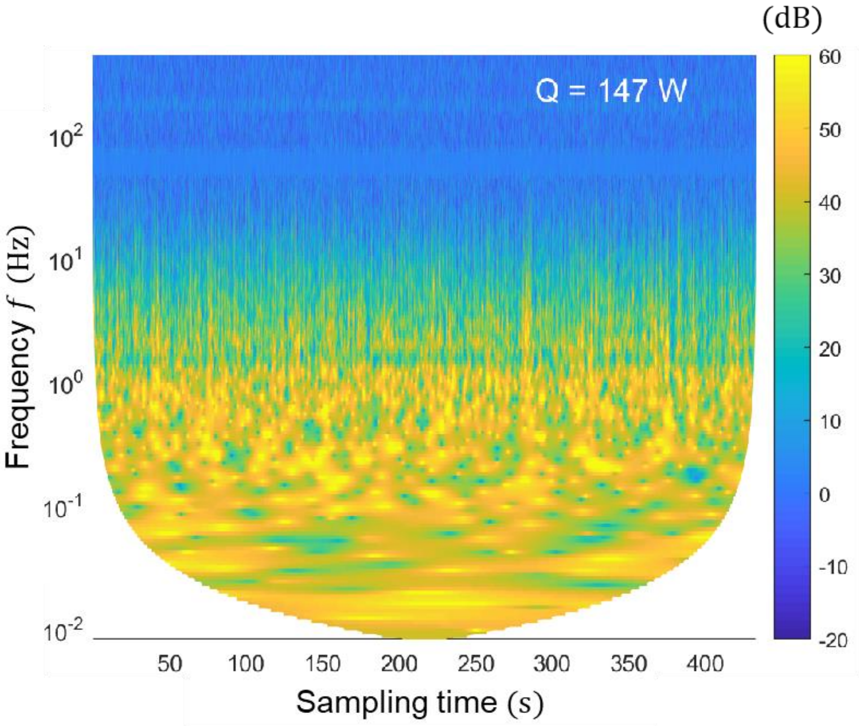

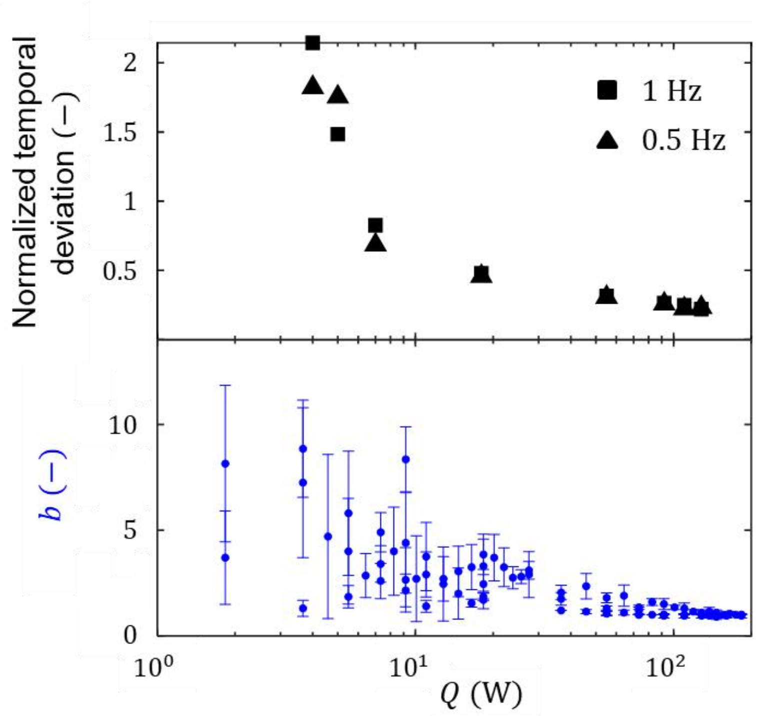

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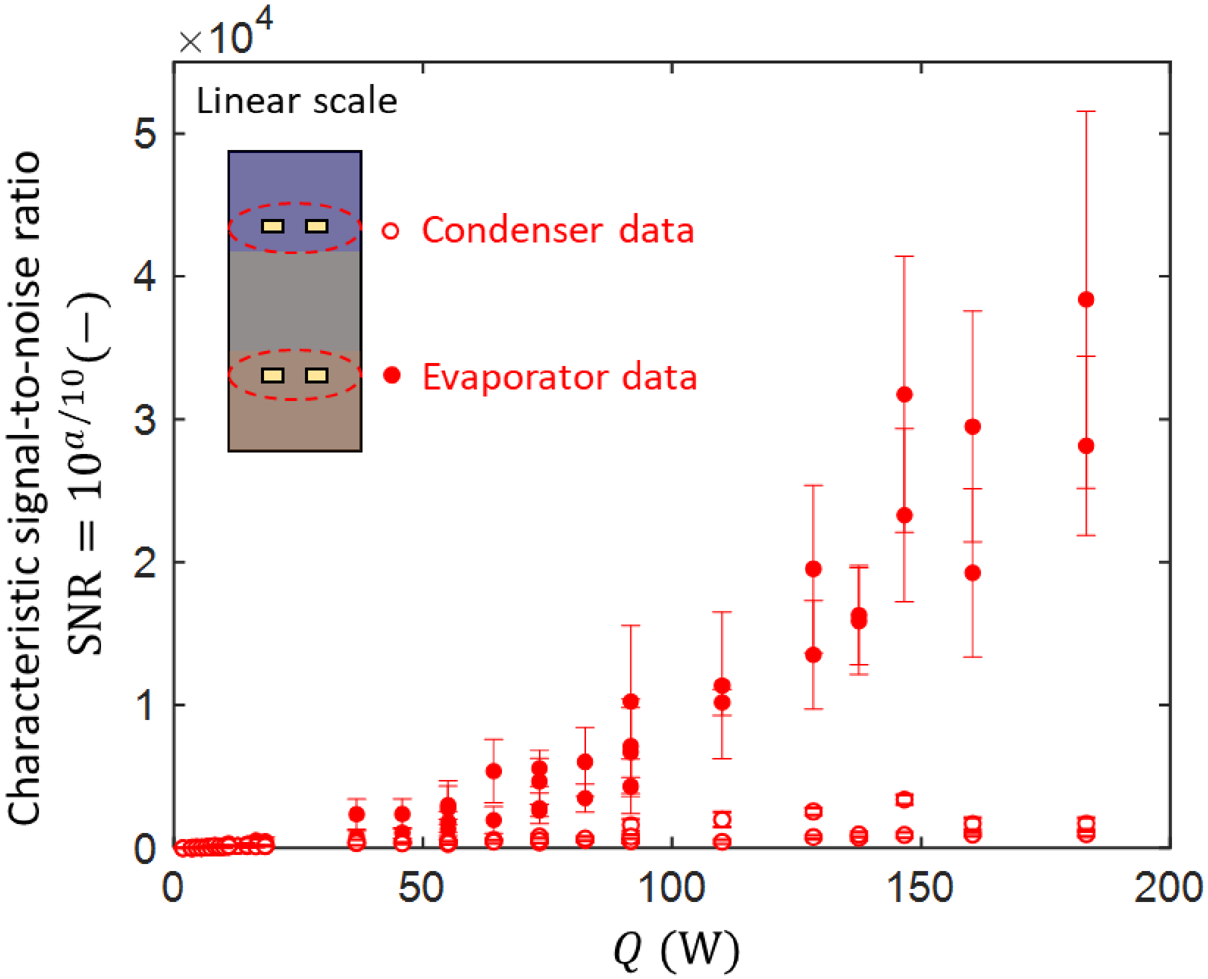
Different behavior at the evaporator and condenser



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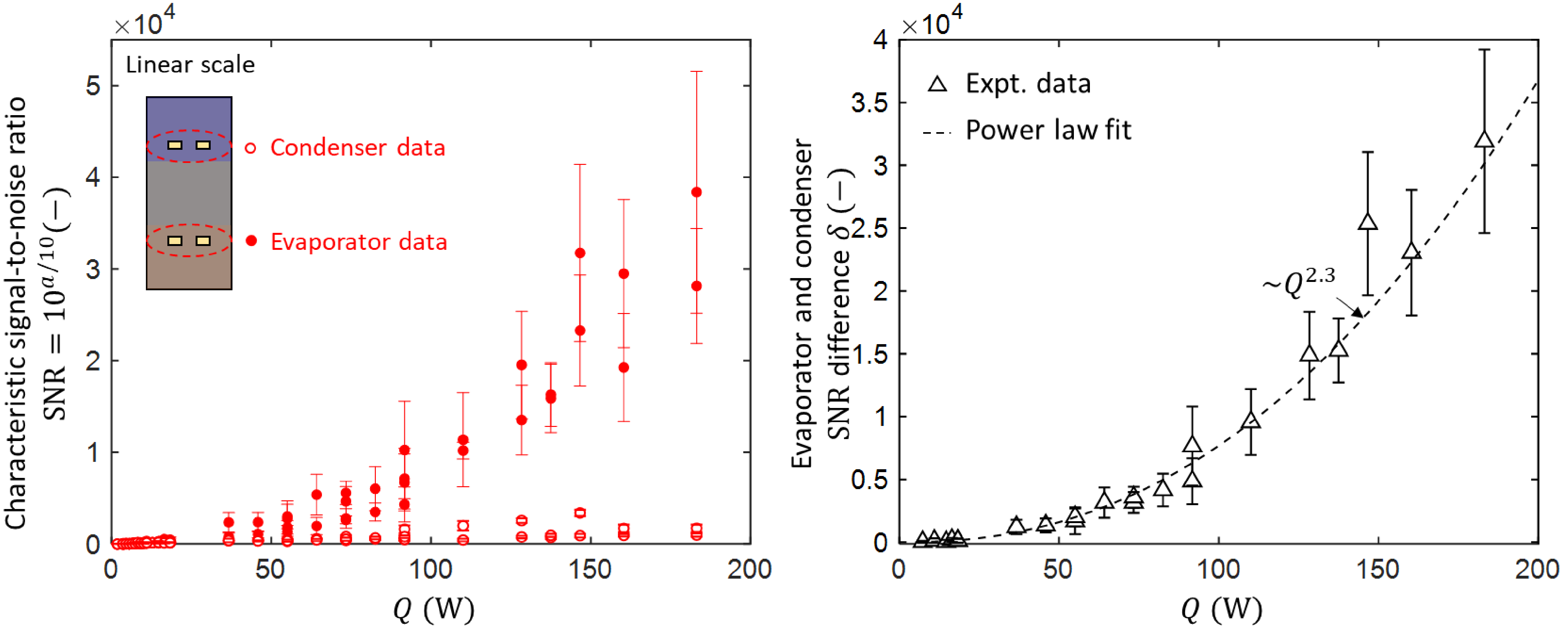
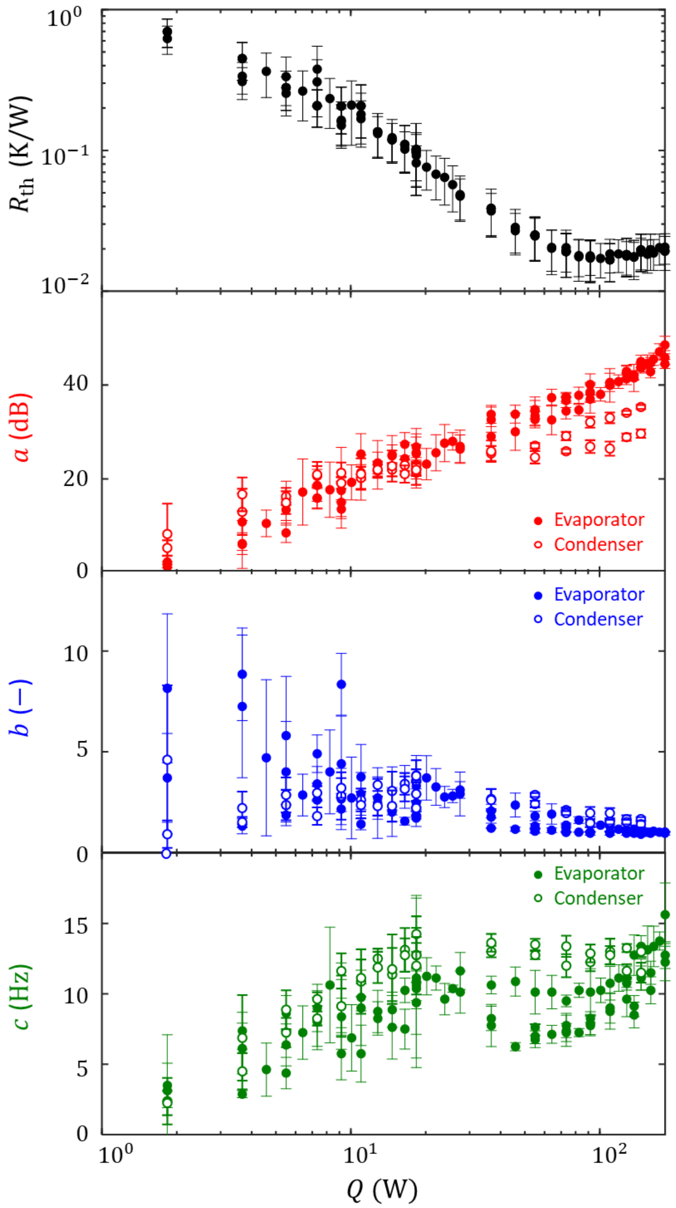


Summary

- Measured the thermal and strain response of an ammonia-filled OHP from 0 to 200 W
- Identified three parameters to quantify frequency response in start up and stable operation ranges
  - a: characteristic signal-to-noise ratio
  - b: rate of frequency response decay
  - c: characteristic frequency
- Intermittency is reduced as operation transitions from the start-up ($Q < 10$ W) to the stable operating regime ($Q > 10$ W)
- Stronger strain signals indicating pressure fluctuations at the evaporator section may be indicative of nucleate boiling



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